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Grand Challenges in Social Physics: In Pursuit of Moral Behavior

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Methods of statistical physics have proven valuable for studying the evolution of cooperation in social dilemma games. However, recent empirical research shows that cooperative behavior in social dilemmas is only one kind of a more general class of behavior, namely moral behavior, which includes reciprocity, respecting others' property, honesty, equity, efficiency, as well as many others. Inspired by these experimental works, we here open up the path toward studying other forms of moral behavior with methods of statistical physics. We argue that this is a far-reaching direction for future research that can help us answer fundamental questions about human sociality. Why did our societies evolve as they did? What moral principles are more likely to emerge? What happens when different moral principles clash? Can we predict the break out of moral conflicts in advance and contribute to their solution? These are amongst the most important questions of our time, and methods of statistical physics could lead to new insights and contribute toward finding answers.

Keywords: cooperation, social dilemma, public good, statistical physics, network science, evolutionary game theory, moral behavior, reciprocity

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1. INTRODUCTION

Our time now is unique and special in that we are arguably richer, safer, and healthier than ever before [1, 2], but simultaneously, we are also facing some of the greatest challenges of our evolution. Climate change, the depletion of natural resources, staggering inequality, the spread of misinformation, persistent armed conflicts, just to name a few examples, all require our best efforts to act together and to renounce part of our individual interests for the greater good. Understanding when, why, and how people deviate from their best self-interest to act pro-socially, benefitting other people and the society as a whole, is thus amongst the most important aims of contemporary scientific research.

Pro-social behavior can come in many forms, the most studied of which is cooperation. Indeed, cooperation is so important that many have contended that our capacity to cooperate at large scales with unrelated others is what makes human societies so successful [3–14]. Moreover, the psychological basis of cooperation, *shared intentionality*, that is, "the ability and motivation to engage with others in collaborative, co-operative activities with joint goals and intentions" is what makes humans *uniquely* human, as it is possessed by children, but not by great apes [15].

Although human cooperation is believed to originate from our evolutionary struggles for survival [16], it is clear that the challenges that pressured our ancestors into cooperation today are gone. Nevertheless, we are still cooperating, and on ever larger scales, to the point that we may deserve being called "SuperCooperators" [17]. Taking nothing away from the immense importance of cooperation for our evolutionary success and for the wellbeing of our societies, recent empirical research shows, however, that to cooperate is just a particular manifestation of moral behavior [18]. And while methods of statistical physics have been used prolifically to study cooperation [14], other forms of moral behavior have not. Our goal here is to discuss and outline the many possibilities for future research at the interface between physics and moral behavior, beyond the traditional framework of cooperation in social dilemmas.

2. COOPERATION

To study cooperative behavior, scientists use social dilemma games, such as the prisoner's dilemma [19], the stag hunt [20], or the public goods game [21]. In these games, players have to decide whether to cooperate or to defect: cooperation maximizes the payoff of the group, while defection maximizes the payoff of an individual. This leads to a conflict between individual and group interests, which is at the heart of each social dilemma, and in particular at the heart of the cooperation problem.

Since cooperating is not individually optimal, cooperative behavior cannot evolve among self-interested individuals, unless other mechanisms are at play. Several mechanisms for the evolution of cooperation have been identified and studied, including kin selection [22], direct reciprocity [23], indirect reciprocity [24], social preferences [25–28], the internalization of social heuristics [29], translucency [30], cooperative equilibria [12, 31, 32], as well as many others.

One realistic mechanism for the evolution of cooperation is network reciprocity. Everyday interactions among humans do not happen in a vacuum. We are more likely to interact and cooperate within our network of family members, friends, and coworkers, and we rarely interact, let alone cooperate, with strangers. One can formalize this situation by assuming that individuals occupy the vertices of a graph and interact only with their neighbors. Can this spatial structure promote the evolution of cooperation? The answer is yes [33]. And the intuition is that, in this setting, cooperators can form clusters and protect themselves from the invasion of defectors [34–36]. These "games on graphs are difficult to analyze mathematically," but "are easy to study by computer simulations" [9]. Games on networks present the natural setting in which one can apply the techniques and methods of statistical physics and network science to study cooperation [37, 38], as well as other forms of moral behavior.

3. STATISTICAL PHYSICS OF HUMAN COOPERATION

Methods of statistical physics have come a long way in improving our understanding of the emergence of cooperation and the phase transitions leading to other counterintuitive evolutionary outcomes. Research has revealed that these depend sensitively on the structure of the interaction network and the type of interactions, as well as on the number and type of competing strategies [39–49]. Aspects particularly relevant to human cooperation have also been studied in much detail [14]. The workhorse behind this research has been the spatial public goods game [50, 51], with extensions toward different forms of punishment [52–58], rewarding [59–62], and tolerance [63], to name just some examples. The Monte Carlo method is thereby typically used [64], which ensures that the treatment is aligned with fundamental principles of statistical physics, enabling a comparison of obtained results with generalized mean-field approximations [65–67] and a proper determination of phase transitions between different stable strategy configurations [45]. The goal is to identify and understand pattern formation, the spatiotemporal dynamics of solutions, and the principles of self-organization that may lead to socially favorable evolutionary outcomes.

An example of an impressively intricate phase diagram, obtained from studying an 8-strategy public goods game with diverse tolerance levels, is presented in Figure 1 of Szolnoki and Perc [63]. There, it can be observed that the higher the value of the multiplication factor in the public goods game, the higher the tolerance can be, and vice versa. This observation resonates with our naive expectation and perception of tolerance in that overly tolerant strategies cannot survive in the presence of other less tolerant strategies. From the viewpoint of the considered evolutionary game this is not surprising, because players adopting the most tolerant strategy act as loners only if everybody else in the group is a defector. And such sheer unlimited tolerance is simply not competitive with other less tolerant strategies. Also, if the cost of inspection is too high, or if the value of the multiplication factor is either very low or very high, then tolerant players cannot survive even if they exhibit different levels of tolerance.

While it is beyond the scope of this work to go further into details, it should be noted that phase diagrams as the one presented in Figure 1 of Szolnoki and Perc [63] provide an in-depth understanding of the evolutionary dynamics and of the phase transitions that lead from one stable strategy configuration to the other. The key for obtaining accurate locations of phase transition points and the correct phases is the application of the stability analysis of competing subsystem solutions [64]. A subsystem solution can be formed by any subset of all the competing strategies, and on their own (if separated from other strategies) these subsystems solutions are stable. This is trivially true if the subsystem solution is formed by a single strategy, but can be likewise true if more than one strategy forms such a solution. The dominant subsystem solution, and hence the phase that is ultimately depicted in the phase diagram as the stable solution of the whole system, can only be determined by letting all the subsystem solutions compete against each other.

By means of this approach, several important insights have been obtained. By peer-based strategies, for example, we note the importance of indirect territorial competition in peer punishment [68], the spontaneous emergence of cyclic dominance in rewarding [59], and an exotic first-order phase transition observed with correlated strategies [69]. By institutionalized strategies, we have the fascinating spatiotemporal complexity that is due to pool punishment [53], while in the realm of self-organization of incentives for cooperation, we have the elevated effectiveness of adaptive punishment [54], the possibility of probabilistic sharing to solve the problem of costly punishment [56], and the many evolutionary advantages of adaptive rewarding [61]. With antisocial strategies, we have the restoration of the effectiveness of prosocial punishment when accounting for second-order free-riding on antisocial punishment [58], and the rather surprising lack of adverse effects with antisocial rewarding [62].

While this is just a short snippet of statistical physics research concerning human cooperation, it hopefully showcases successfully the potency of the approach for studying complex mathematical models that describe human behavior, thus recommending itself also for relevantly studying other types of moral behavior to which we attend to in what follows.

4. MORAL BEHAVIOR

Empirical research has indeed shown that cooperation in social dilemmas is only one facet of a more general class of behavior – moral behavior. When subjects are asked to report what they think is the morally right thing to do in social dilemmas, they typically answer: "to cooperate" [18].

Morality is universal across human societies. Virtually all societies adopt behavioral rules that are presented to the people as moral principles. But where do these rules come from? A classical non-scientific explanation, still adopted by many societies and religious thinkers, is that they are emanated directly from God. However, in recent years, social scientists have been developing a scientific theory of morality, according to which morality evolved as a a mechanism "to promote and sustain cooperation" [70]. As psychology-star Michael Tomasello put it: "human morality arose evolutionarily as a set of skills and motives for cooperating with others" [71]. Similar positions have also been put forward in Rawls [72], Mackie [73], Wong [74], Rai and Fiske [75], Curry [76], and Curry et al. [77]. However, the word "cooperation" in these statements does not refer only to cooperation in social dilemmas. How does this general form of cooperation translates into specific behaviors?

A recent study exploring morality in 60 societies across the world found that seven moral rules are universal: love your family, help your group, return favors, be brave, defer to authority, be fair, and respect others' property. Although, what is not universal is how they are ranked [77]. Of course, not all these rules are easy to study using simple games on networks, but some are. For example, "returning favors" can be studied using a sequential prisoner's dilemma, in which the players do not choose their strategy simultaneously, but sequentially. Alternatively, it can be studied using the trust game [78]. In the trust game, player 1 starts with a sum of money and has to decide how much of it, if any, to transfer to player 2. Any amount transferred gets multiplied by a factor larger than 1 and handed to player 2. Then player 2 has to decide how much of it to keep and how much of it to return to player 1.

Similarly, "help your group" can be studied using games with labeled players, in which agents come with a label representing the group(s) they belong to [79]. "Fairness" can be studied using the ultimatum game [80], as has already been done along these lines [45, 81–90], or the dictator game [91]. "Respect others' property" can be studied using games with special frames, as, for example, the Dictator game in the Take frame, for which it is known that taking is considered to be more morally wrong than giving [92].

Beyond these seven rules, there are other forms of moral behavior that are worth studying, as, for example, "honesty." A common game theoretic paradigm to study honest behavior is the sender-receiver game [93]. In this game, player 1 is given a private information (for example, the outcome of a die) and is asked to communicate this piece of information to player 2. Player 1 can either communicate the truthful piece of information, or can lie. The role of player 2 is to guess the original piece of information. If player 2 guesses the original piece of information, then players 1 and 2 are both paid according to some option A. Conversely, if player 2 does not guess the original piece of information, then players 1 and 2 are both paid according to option B. Crucially, only player 1 knows the payoffs associated with options A and B. A variant of this game in which player 2 makes no choice has also been introduced and studied [94, 95], in order to avoid the confound of *sophisticated deception*, that is, players who tell the truth because they believe that player 2 will not believe them [96].

Other important forms of moral behavior that ought to be investigated are "equity," that is, a desire to minimize payoff differences among players; "efficiency," that is, a desire to maximize the total welfare; and "maximin," that is, a desire to maximize the worse off payoff. These types of behavior are usually studied using simple distribution experiments, in which people have to decide between two or more allocations of money [18, 27, 28, 97, 98].

5. DISCUSSION

Methods of statistical physics and network science have proven to be very valuable for successfully studying the evolution of cooperation in social dilemma games. However, empirical research shows that this kind of behavior is only one form of a more general class of moral behavior. The later includes love your family, help your group, return favors, be brave, defer to authority, be fair, respect others' property, honesty, equity, and efficiency, as well as many others. We have outlined a set of games and mathematical models that could be used efficiently to study particular aspects of some of these forms of moral behavior.

Taken together, the application of statistical physics to study the evolution of moral behavior has the potential to become a flourishing and vibrant avenue for future research. We believe so for two reasons. In the first place, it would allow us to understand why our societies evolved as they did and which moral principles are more likely to evolve. Secondly, since many social conflicts are ultimately conflicts between different moral positions [99–101], exploring the evolution of moral behavior could allow us to predict in advance the consequences of a moral conflict, and suggest strategies to avoid it or, in case it is unavoidable, strategies to minimize its costs. We hope that at least parts of our vision will be put to practice in the near future.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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